HSIS

HIGHWAY SAFETY INFORMATION SYSTEM

The Highway Safety Information System (HSIS) is a multi-State safety database that contains crash, roadway inventory, and traffic volume data for a select group of States. The participating States—California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, Utah, and Washington—were selected based on the quality of their data, the range of data available, and their ability to merge the data from the various files. The HSIS is used by FHWA staff, contractors, university researchers, and others to study current highway safety issues, direct research efforts, and evaluate the effectiveness of accident countermeasures.

U.S. Department of Transportation
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Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike • McLean, VA 22101-2296

SUMMARY REPORT

Safety Effects of Using Narrow Lanes and Shoulder-Use Lanes to Increase the Capacity of Urban Freeways

As traffic volumes grow on urban freeways, highway agencies face an ongoing challenge to maintain efficient traffic operations and acceptable levels of service. Increasing the capacity of a freeway by adding a lane can be difficult and expensive if it involves widening the existing roadbed, regrading roadside areas, and/or acquiring additional right-of-way. A number of highway agencies, however, have implemented projects in which a travel lane is added on an urban freeway by restriping the traveled way with narrower lanes, converting all or part of the shoulder to a travel lane, or a combination of both. The traffic operational benefits of such conversions are immediate and obvious, but the safety effects are uncertain. This study addresses these safety effects.

Literature Review

McCasland[1] evaluated two freeway segments in Houston, TX on which narrower lanes and a narrower outside shoulder were used to create an additional travel lane. Reductions in the accident rate per million vehicle-kilometers (veh-km) were found using a Poisson comparison of means test. Urbanik and Bonilla[2] evaluated similar projects on urban freeway segments in California using a two-sample t-test. Statistically significant changes in the accident rate were found for three of the 10 projects evaluated. Two projects experienced statistically significant reductions in the accident rate, but one project experienced a statistically significant increase. In particular, the entire accident rate increase for this project occurred near the downstream end of the segment. There are concerns that both evaluations addressed accident rate rather than accident frequency and did not compensate for regression to the mean, both of which could have distorted the safety benefits.

The current study attempts to account for these possible biases.

Methodology

Databases Used

Because of the need for adequate periods both before and after treatment, the study analyzed data on urban freeway sites in California—78.7 kilometers (km) (48.9 miles(mi)) of treatment sites, 31.1 km (19.3 mi) of untreated sites downstream from treatment sites, and 398.5 km (247.6 mi) of untreated reference sites similar to the treatment sites. Supplemental data was also collected on sites immediately upstream of the treatment sites. Sites in all three groups had median barriers present. All crash, traffic volume, and roadway inventory data were extracted from 1991–2000 California files in the Federal Highway Administration's (FHWA) Highway Safety Information System (HSIS).

Research Design

All treatments involved converting either four lanes in one direction to five lanes, or five lanes in one direction to six lanes. New travel lanes were developed from existing pavement width by converting paved shoulders to travel-lane width, narrowing existing lanes by restriping, or a combination of the two. The treatments had various combinations of before-and-after geometrics (i.e., different amounts of shoulder conversion and lane narrowing), which were grouped into "bundles" for analysis. The primary bundles in both classifications involved narrowing only the inside shoulder, and either leaving the lane width at 3.7 meters (m)(12 feet (ft)) or narrowing the lanes to at least 3.4 m (11.2 ft). In all but one bundle, the added lane was a high occupancy vehicle (HOV) lane during at least some part of the day.

The goal of the study was to examine the effects of the treatment on three measures of effectiveness:

- Total accidents (fatal, injury, and property-damage-only (PDO) accidents, including both towaway and non-towaway accidents).
- Fatal, injury, and PDO towaway accidents (excluding PDO non-towaway accidents).
- Fatal and injury accidents (excluding all PDO accidents).

In addition to examining changes in these three measures for all four- to five-lane conversions combined and all five- to six-lane conversions combined, the authors also attempted to examine the effects of different "bundle" types, different crash types (e.g., sideswipe crashes), and the number of interchange ramps in a section. They also studied possible upstream effects of changes in flow and downstream effects of "accident migration" when the new lane was dropped.

All treatments were implemented in 1993, and crash, traffic, and inventory data were available in HSIS from 1991–2000, so the data allowed for a before-and-after study. To control for possible regression to the mean and other biases, the empirical Bayes (EB) methodology described by Hauer[3,4] was used. Here, a prediction of what would have happened at the treatment sites in the after period *without treatment* is based on a weighted combination of two factors: (1) the frequency of crashes on the treated sites in the before period, and (2) crash-frequency predictions from regression models developed with data from the untreated reference sites. The prediction of what would have happened without treatment is then compared to what actually happened with treatment to estimate the safety effect of the treatment. The methodology corrects for the regression bias, changes in traffic volume at the treatment sites, and other possible confounding factors. Details of the methodology are in the paper referenced at the end of this summary.

Data Collection

As noted above, crash, inventory, and traffic data for treatment, downstream, and reference sites were extracted from

TYPE OF SITE	NUMBER OF LANES	NUMBER OF SITES	TOTAL LENGTH OF SITES (MI)	AADT[a] (VEH/DAY) (1994)			NUMBER OF RAMPS		
				MINIMUM	MEAN	MAXIMUM	ON-RAMPS	OFF-RAMPS	TOTAL
Treatment									
	4 to 5[b]	79	36.4	79,000	104,081	128,000	60	51	111
	5 to 6b	45	12.5	77,000	107,497	126,500	14	15	29
	Total	124	48.9	77,000	104,951	128,000	74	66	140
Downstream									
	4 to 5[c]	45	11.4	62,5000	103,267	128,000	28	23	51
	5 to 6[c]	33	7.9	77,000	114,121	126,500	14	19	33
	Total	78	19.3	62,500	107,859	128,000	42	42	87
Reference									
	3[d]	92	45.7	5,600	63,958	142,500	205	222	427
	4[d]	270	138.6	14,250	79,965	164,000	559	534	1,093
	5[d]	128	63.4	48,500	109,245	164,000	154	149	303
	Total	490	247.7	5,600	81,227	164,000	918	905	1,823

Table 1. Descriptive statistics of evaluation sites.

[a]Annual average daily traffic volume (veh/day) for one direction of travel.
[b]Number of lanes before and after the project (i.e., conversion type).
[c]Number of lanes before and after the project on the adjacent treated site.
[d]Number of lanes on the reference site.

1 mile = 1.6 kilometers

the 1991–2000 California HSIS files. Table 1 presents basic descriptive statistics for the three types of sites, and table 2 presents the crash data for the before-and-after periods at the treatment sites. For all three types, the mileage was divided into "homogeneous sites" for analysis purposes, with each site being homogeneous for conversion type (number of lanes for the reference sites) and traffic volume. All of the treatment and downstream sites were located in two southern California counties, and the reference sites were located in these two counties plus four surrounding counties.

Analysis

As noted above, one component of the prediction of after-period accident frequencies at the treatment sites *without treatment* is a regression model (i.e., a safety performance function (SPF)) developed using data from the untreated reference sites. In this study, SPFs using a negative-binomial distribution were developed with the following primary independent variables:

- Annual average daily traffic (AADT).
- Segment length.
- AADT and segment length combined into a single exposure variable as EXPO equals (AADT times segment length) divided by 10^6 in million vehicle miles (MVM).

Examination of several model forms indicated that the most appropriate and useful models had the following form:

$$\text{Expected number of accidents per year} = \exp(\beta_1) \times AADT^{\beta_2} \text{ (segment length)}$$

The regression coefficients β_1(intercept) and β_2(exponent of AADT), the overdispersion parameter of the negative binomial distribution, and two goodness-of-fit measures (i.e., the ordinary multiple correlation coefficient, R^2, and the Freeman-Tukey coefficient, R_{FT}^2) were estimated by the method of maximum likelihood using a commercially available SAS® statistical analysis software named PROC GENMOD.[5]

While the EB approach compensates for regression to the mean and adjusts for the effect on safety of changes in AADT over time, the effect on safety of changes in other factors over time (e.g., accident reporting practices, demography, weather) also needs to be addressed. This was accomplished by developing a series of yearly calibration factors to ensure that the SPF-predicted and observed accidents at each treated site during the before period are the same[4] and using these calibration factors to adjust the predicted accidents for each specific year. For the examination of off- and on-ramp effects, modified SPFs including an independent variable for the number of ramps were developed.

Results

Estimated Safety Effects of Four- to Five-Lane and Five- to Six-Lane Conversions

The results of the primary analyses for different crash injury levels within the two categories of treatment sites are shown in table 3. Note that the designation of the statistical significance of the change in crash frequency is based on the ratio of the mean treatment effect to its standard error. Hauer[3] recommends that a ratio of 2.0 or greater be used in judging the results of the EB analysis. Although not a formal test of significance, this could be equated to an approximate 98 percent (one-sided) test.

The EB analysis results in table 3 indicate that the four- to five-lane conversions, on the average, resulted in a statistically significant increase in accident frequency of 10 to 11 percent. The five- to six-lane conversion projects resulted in an increase in accident frequen-

Table 2. Accident frequencies at treatment sites.

CONVERSION TYPE	BEFORE PERIOD (1991-1992)							AFTER PERIOD (1994-2000)						
	NUMBER OF ACCIDENTS					AVERAGE AADT[a] (VEH/DAY)	EXPOSURE (10^6 VEH-MI)	NUMBER OF ACCIDENTS					AVERAGE AADT[a] (VEH/DAY)	EXPOSURE (10^6 VEH-MI)
	FATAL	INJURY	PDO TOWAWAY	PDO NON-TOWAWAY	TOTAL			FATAL	INJURY	PDO TOWAWAY	PDO NON-TOWAWAY	TOTAL		
4 to 5 lanes	8	629	201	947	1,785	105,461	2,804.5	26	2,310	2,204	3,103	7,643	107,267	9,983.7
5 to 6 lanes	2	243	71	340	656	110,605	1,020.0	13	809	731	1,048	2,601	111,874	3,613.3
Total	10	872	272	1,287	2,441	106,772	3,824.5	39	3,119	2,935	4,151	10,244	108,441	13,597.0

[a] AADT is for the treated direction of travel only.

cy of 3 to 7 percent, not statistically significant. The sample size for five- to six-lane conversions was about half that for four- to five-lane conversions, so the five- to six-lane analysis would be less likely to result in statistically significant results as reflected by the larger standard errors.

Supplemental Results

The examination of crash types (both changes in single- and multivehicle proportions and in individual crash types) indicated no statistically significant change on the treatment sites. In general, the results show that the frequency of rear-end collisions increased after project implementation. The frequency of sideswipe accidents increased for the four- to five-lane conversions, but decreased for the five- to six-lane conversions (which may help explain the difference in effects in the primary analysis above).

The analyses of the individual "bundle" types did not show differences between bundles that could be used in deciding how best to apply the treatment. The analysis of ramp locations did not show statistically significant results, but it was interesting to note that crash frequency increased both near and away from ramps on the four- to five-lane conversions and near ramps in the five- to six-lane conversions. Crash frequency decreased in the five-lane conversion sites away from ramps.

Table 3. Empirical Bayes analysis results for primary evaluation of specific conversion types.

CONVERSION TYPE	MEASURE OF EFFECTIVENESS/ DEPENDENT VARIABLE	NUMBER OF SITES	PERCENT CHANGE IN ACCIDENT FREQUENCY		RATIO[b]	SIGNIFICANT?[c]
			MEAN[a]	STANDARD ERROR		
4 to 5 lanes						
	Total accidents	79	10.96	2.88	3.8	Yes
	Fatal, injury, and PDO towaway accidents	78	9.67	3.89	2.5	Yes
	Fatal and injury accidents	78	10.59	4.56	2.3	Yes
5 to 6 lanes						
	Total accidents	43	3.02	4.56	0.7	No
	Fatal, injury, and PDO towaway accidents	45	3.71	6.08	0.6	No
	Fatal and injury accidents	45	7.08	7.22	1.0	No

[a] A positive mean percent change indicates an increase in accident frequency, and a negative mean indicates a decrease.

[b] Ratio of mean percent change in accident frequency to standard error of percent change in accident frequency.

[c] Significant if ratio ≥2, and not significant if ratio <2.

The examination of possible "accident migration" to adjacent downstream sites indicated a nonsignificant increase for the four- to five-lane conversions of 5 to 12 percent, and a statistically significant 17 to 21 percent increase downstream from the five- to six-lane conversions. An effect that potentially offsets the accident migration on the five- to six-lane conversions was a nonsignificant decrease in crash frequencies for freeway segments upstream of the conversion site.

Discussion

The analysis results indicate that narrow-lane or shoulder-use-lane projects on urban freeways increase accident frequencies for four- to five-lane conversion projects. Such conversions may increase accident frequencies for five- to six-lane conversion projects as well, but the results for those projects were not statistically significant. Because of the different findings for these two types of conversions, the results obtained are difficult to generalize to urban freeways as a whole.

One possible explanation for the increase in accident frequency on conversion projects is that the added lanes in most of the projects were HOV lanes. Speed differentials between the main lanes and HOV lanes on freeways have the potential to increase sideswipe and lane-changing accidents, although this effect has not been satisfactorily quantified in the literature. The crash type results in this study indicated a nonsignificant increase in sideswipe collisions on the four- to five-lane conversions, but a decrease on the five- to six-lane conversions. If this is indeed true, it may help explain why the results differ between the two classes.

The results also suggest that, at least for the five- to six-lane conversions, the effect of the project may have been to dissipate congestion upstream of the treatment site by removing the treatment site as a bottleneck. It is possible that the effects of the four- to five-lane conversions have been partially because of the displacement of a bottleneck as well. The bottleneck may have been transferred to a location downstream of the treatment site, with a corresponding increase in accident frequency at that location and possibly within the treatment site itself.

In summary, the findings are more complex than expected. Differences may exist in the crash-related effects of lane conversion treatments at four-lane versus five-lane sites. The differences between road classes observed may be explained by differences in traffic operations (e.g., speeds, lane-changing behavior) that could not be analyzed in this study. In addition, the observed increases in accident frequency cannot necessarily be attributed to the use of narrower lanes or the conversion of a shoulder to a travel lane. The use of the added lanes as HOV lanes, which may introduce a difference in speed between adjacent lanes, may be another explanation for the increase in accidents. The analysis results also suggest that the conversion projects may decrease accident frequencies upstream of the project and increase accident frequencies within and downstream of the project because the projects may result in the relocation of a traffic operational bottleneck. These various effects on safety are confounded in the data and could not be separated in this study.

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FOR MORE INFORMATION

This research was conducted by Karin M. Bauer, Douglas W. Harwood, and Karen R. Richard of the Midwest Research Institute and Warren E. Hughes of BMI-SG. The final report, "Safety Effects of Using Narrow Lanes and Shoulder-Use Lanes to Increase the Capacity of Urban Freeways," appears in the Transportation Research Board's *Transportation Research Record: Journal of the Transportation Research Board No. 1897*, 2004.

For more information about HSIS, contact Carol Tan, HSIS Program Manager, HRDS, 202–493–3315, carol.tan@fhwa.dot.gov.

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